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Title: Automated estimation of the DARHT radiographic spot size from spatially modulated images

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AUTOMATED ESTIMATION OF THE DARHT RADIOGRAPHIC SPOT SIZE FROM SPATIALLY MODULATED IMAGES

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BACKGROUND

The quality of a radiographic image is limited by the finite volume of the region from which x-rays are emitted from the Bremsstrahlung target, commonly called the spot. The spot size can be altered in extent and symmetry by tuning the properties of the electron beam focusing system. At DARHT, the spot size is currently experimentally calculated by analyzing radiographic images of a pinhole target. This method requires background subtraction to be performed, and a generalized automated method to do so has not been developed. The current method requires the operator to view two Gaussian fits to a vertically and horizontally integrated image of a pinhole object, and then to subtract a flat line background from both simultaneously until the tails in the distribution are not visible. Once this background subtraction is complete, the width of the final Gaussian is used in subsequent calculations to arrive at a spot size. The current method assumes a symmetric, centered spot with a Gaussian intensity profile, which all are compounding approximations leading to difficulties in the spot determination, however the main source of error is variability in how the operator determines when background subtraction is acceptable. The quality of the fit is influenced by tails in the distribution that result from subtracting a flat background from a background shape that is not quite flat. The subtraction is done by eye and we found it can introduce 10-20% differences on the reported spot size. Conducting the spot size measurement in this way has been acceptable because typically the same operator was always doing the background subtraction, and so the result provided confidence that the DARHT beam focusing was acceptable, based on the operator’s experience, to proceed with a radiographic experiment. The method presented here is an attempt to remove the operator variability in favor of an automated measurement of the radiographic spot size. We present the mathematical basis of the new method and then examine performance relative to the pinhole method.

METHOD

Several methods of spot size determination relevant to DARHT, including the spatially modulated experimental method, are described in [1]. The mathematical basis for utilizing the minimum resolvable spatial frequency to calculate the spot size is described in [2], with the result that the spot size a is related to the minimum resolvable spatial frequency $f_{\min}$ and the system magnification factor M by the relation

$$a = \frac{M}{f_{\min}(M-1)} \tag{1}$$

The DARHT magnification M, defined by the positions of the source, object and detector, is 3.947. To determine $f_{\min}$, an image of a spatially modulated target can be automatically analyzed by software. For demonstration purposes we use images of the KTO object (see Figure 1), which is usable but not ideal for this purpose since the feature size is localized and discrete rather than uniform and continuous. We discuss the design of an ideal object later.

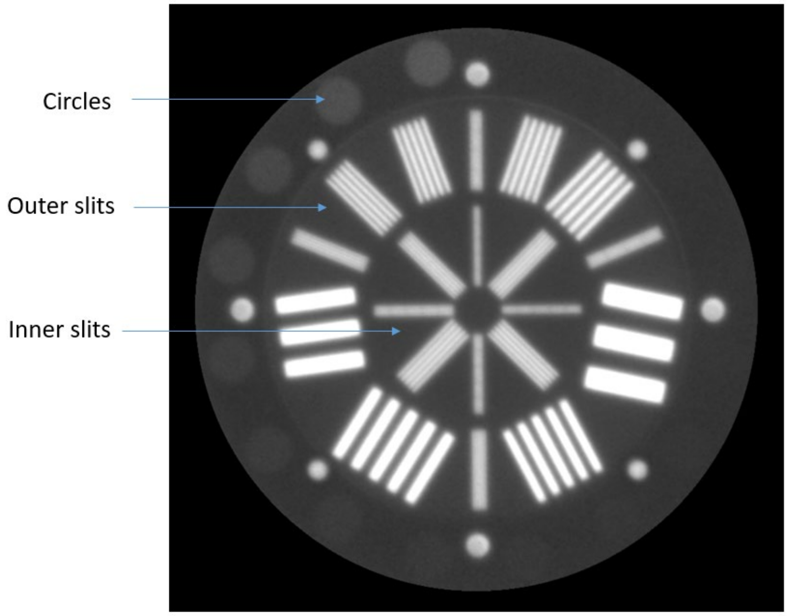

Figure 1 - DARHT radiograph of the KTO. The slits are rectangular through-cuts, 1.5cm in length and with feature width equal to the spacing and ranging from 0.124 to 3.99 mm. The circles are varying depth features and are not relevant to this analysis.

The image is automatically analyzed by calculating the contrast, *C,* of each set of spatial features of frequency f using the local extrema within each feature set in the following way

$$C(f) = \frac{I(f)_{\max} - I(f)_{\min}}{I(f)_{\max} + I(f)_{\min}} \quad (2)$$

This set of image contrast values is used to interpolate a value for *f* at *C* = 0.01, representing the 1% limit of human-perceptible contrast in the KTO image. The 1% threshold was determined experimentally from DARHT images and is a standard threshold value in the literature [3]. With these values determined, calculation of the spot size is possible with Eq. (1).

RESULTS

We wrote a software routine to find local extrema and calculate the contrast in the image for each feature set. The input is a KTO image in the standard DARHT orientation, pre-processed by flat-fielding, dark frame subtraction and de-warping. Table 1 shows contrast results for five contemporaneous DARHT images of the KTO. For some very dense feature sets, contrast measurements are not possible due to a lack of local extrema, and in this case no contrast value is given in the table. Highlighted in bold are the contrast values for each image that bound the threshold C = 0.01. The contrast is varying rapidly enough with spatial frequency that we can interpolate between these values to find an estimate of the spatial frequency at the threshold value.

Table 1 – Contrast for discrete spatial frequencies in DARHT KTO images

Slit width (in.)	Spatial Freq. (mm^{-1})	Inferred Spot Size (mm)	Contrast				
			Axis 1	Axis 2 Time 1	Axis 2 Time 2	Axis 2 Time 3	Axis 2 Time 4
0.0049	4.017	0.33	-	-	-	-	-
0.0059	3.336	0.40	-	-	-	-	-
0.0069	2.853	0.47	-	-	-	-	-
0.0079	2.492	0.54	-	-	-	-	-
0.0089	2.212	0.61	-	-	-	-	-
0.0100	1.969	0.68	-	-	-	-	-
0.0110	1.790	0.75	-	-	-	-	-
0.0120	1.640	0.82	-	-	-	-	-
0.0140	1.406	0.95	***0.0086***	-	-	-	-
0.0160	1.230	1.09	***0.012***	***0.0034***	-	-	-
0.0180	1.094	1.22	0.032	***0.015***	***0.0068***	-	-
0.0200	0.984	1.36	0.027	0.031	***0.026***	***0.0086***	-
0.0240	0.820	1.63	0.059	0.054	0.046	***0.02***	***0.0096***
0.0280	0.703	1.91	0.084	0.069	0.081	0.041	***0.025***
0.0310	0.635	2.11	0.078	0.095	0.11	0.054	0.048
0.0390	0.505	2.65	0.11	0.18	0.19	0.12	0.1
0.0590	0.334	4.01	0.28	0.3	0.32	0.27	0.24
0.0790	0.249	5.37	0.34	0.35	0.38	0.34	0.33
0.1180	0.167	8.03	0.44	0.41	0.43	0.41	0.42
0.1570	0.125	10.68	0.48	0.44	0.45	0.44	0.44

Table 2 shows the calculated spot size value for each image. Also shown for comparison is the result from the current DARHT pinhole method described earlier. The Axis 1 pinhole method result is an average over three pinhole measurements that were made (1.15 mm, 1.11 mm, and 1.25 mm). The actual pinhole measurements for the Axis 2 images are shown in Figure 2.

Table 2 – Comparison of spot size calculated by the pinhole and the present spatial contrast methods

Image	Pinhole method (mm)	Spatial contrast method (mm)
Axis 1	1.17	1.01
Axis 2 Time 1	1.17	1.16
Axis 2 Time 2	1.22	1.24
Axis 2 Time 3	1.73	1.39
Axis 2 Time 4	1.93	1.64

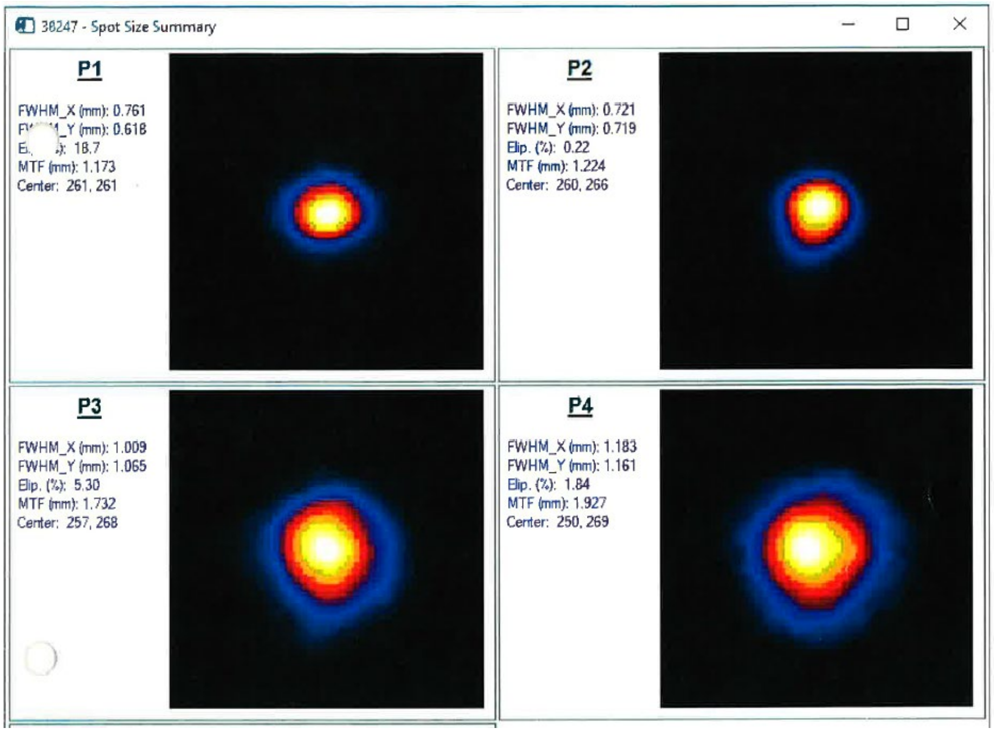

Figure 2 - Pinhole measurements of the Axis 2 spot size (called MTF) for four successive x-ray pulses (P1 - P4).

DISCUSSION

The results in Table 2 show that the proposed method of spot size determination with spatially modulated targets shows promise. The Axis 1 and first two Axis 2 times are nearly identical between the two methods. The final two Axis 2 times are quite a bit different, but there are a few non-optimal factors in both methods: first, the pinhole method does not work as well when the radiographic spot is less symmetrical and less centered, which is usually the case for later time pulses on Axis 2; and second, the KTO is not the best target for this investigation because: (1) there are not enough feature sets around the spatial frequency of interest; (2) the spatial features are restricted to only one angle off the beam; and (3) these features are discrete rather than continuous. It is certain that a more general result for the present method will be obtained with a new target manufactured in the shape of a Siemens star (Figure 3) with the spatial frequency at half-radius near the limiting resolvable spatial frequency of the lowest quality image (~ 0.8 mm^{-1}).

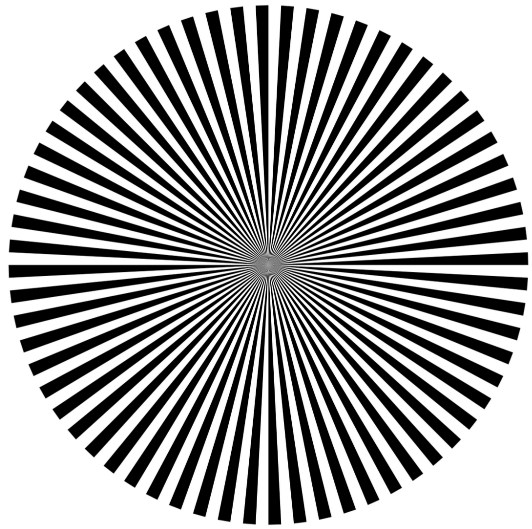

Figure 3 -Siemens star target.

Calibration radiography at DARHT will be simplified with this method because there is no user interaction required, and so we eliminate the variability in background subtraction between different operators. Technically, this method will give a better representation of spot size since there is no assumption of symmetry as in the case of a Gaussian fit to the pinhole data. Also, results of the KTO analysis show that de-warping and demagnification are not critical to this analysis – the results are the same – so in practice, the de-warping grid analysis does not need to be performed prior to the spatial target spot size radiography. This is important to the execution timing of calibration radiography at DARHT. Other benefits of the Siemens star include the potential to generate a modulation transfer function at continuous rather than discrete spatial frequencies.

REFERENCES

[1] Carl Ekdahl, *Characterizing flash-radiography source spots*, J. Opt. Soc. Am. A **28** (12), pp. 2501-2509, December 2011.

[2] G. U. V. Rao, *New method to determine focal spot size of x-ray tubes*, American Journal of Roentgenology Radium Therapy and Nuclear Medicine **111**, pp. 628-632, 1971.

[3] Denis G. Pelli and Peter Bex, *Measuring Contrast Sensitivity*, Vision Research **90**, pp. 10-14. DOI: 10.1016/j.visres.2013.04.015, September 2013.